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AN INVESTIGATION OF OPTIMUM WORK-REST PERIODS
AND THEIR RELATION TO THE ELECTROMYOGRAPHIC MEASUREMENT
OF THE PHYSIOLOGICAL COST OF WORK
FOR THE FOREARM FLEXOR MUSCLES

A THESIS

Presented to

the Faculty of the Graduate Division

by

Herbert Ray Sherrow, Jr.

In Partial Fulfillment

of the Requirements for the Degree

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Approved:

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SUMMARY

It is hypothesized in this research that the muscle action potentials in the forearm flexor muscles are valid measures of the physiological cost of work of the muscles. The objective of this research is to test this hypothesis and to further determine if an optimum scheduling of work-rest cycles exists when the rest period is established as a percentage of the work period. The work period is established as a percentage of an arbitrarily selected base work period of four minutes, with the optimum cycle being that cycle which requires the least physiological cost to the worker. A correlation is thus sought between the muscle action potentials and an optimum work-rest cycle.

Four subjects selected from a graduate student population were tested on a standard hand ergometer task. The subjects performed the standard task at nine different time combinations of work-rest cycles. The total length of each cycle was thirty minutes. Throughout each work period muscle action potentials were recorded from the forearm flexor muscles of each subject. At rest data were not treated in this experiment.

The peak-to-peak amplitudes of the muscle action potentials were analyzed for each subject and work-rest cycle using the analysis of variance technique. The analysis indicated no significant variation between subjects or rest periods; and no significant interaction between subjects, work periods, or rest periods. The variation between work

periods was significant at the ten per cent level of significance. The results indicated that the muscle action potentials in the forearm flexor muscles are not valid indicators of the physiological cost of work under the conditions imposed by this experiment. Because the muscle action potentials do not appear to be valid indicators no conclusions can be drawn concerning the optimum work-rest cycle.

Apparently, a large random error exists in the muscle action potentials and was the primary cause for the lack of significant variation subjects and rest periods. Graphical analysis, used to augment the analysis of variance, indicated a large variation within subjects which may be a major cause of random error.

The recommendation is made that longer periods of work and rest with varying rates of work be attempted over a greater range of experimental levels. It is also recommended that other physiological indicators be used with the same experimental design. Also, since only the forearm flexor muscles were investigated in this research, it is recommended that other muscles, or groups of muscles, be investigated since they may produce muscle action potentials which would be valid predictors of physiological cost of work under dynamic working conditions.

ABBREVIATIONS

EMG	=	Electromyograph
MAP	=	Muscle Action Potential = x = Dependent Variable
EEG/ECG	=	Electroencephalograph/Electrocardiograph
ECG	=	Electrocardiograph

CHAPTER I

INTRODUCTION

The motivation for this research was the result of a research program in the area of physiological costs in industrial environments conducted in the School of Industrial Engineering under the direction of Dr. David C. Ekey.

A major problem in the field of Industrial Engineering is the determination of an objective measure of the physiological cost of work which is done by the worker in the work environment. Because of the complexity of the human machine and the psychological-physiological interactions involved there is, as yet, no operational, quantitative method to measure the physiological cost of work which is being done by the worker. The objective of this research is to determine if an optimum scheduling of work-rest cycles exists such that a given amount of work may be obtained in a fixed time interval with a minimum physiological cost to the worker. The rest periods are determined as a percentage of the preceding work period and the work period is determined as a percentage of a base work period, arbitrarily established as four minutes. It is hypothesized that the electrical potentials in the muscles are an indicator of the worker's physiological cost.

The amount of physiological impairment in the muscles is dependent upon the amount of work and rest to which the muscles are subjected. There is presently much disagreement about the distinction between physiological impairment and "fatigue" of the organism. Bartley and Chute (1) define fatigue in terms of a psychological experience and consider work output as "including all overt activity that is measured either in the laboratory or in industry." Others consider work output as one of the general factors comprising fatigue. Viteles (2) says,

> The word fatigue as used both popularly and scientifically refers to three related phenomena: (1) An overt manifestation in the form of reduced output on the task, known as work decrement, (2) A physiological state, including changes in organic functions and the production of chemical products of fatigue, and (3) A feeling of fatigue or tiredness."

The early experimenters, such as Gilbreth (3) considered a decrement in work output as the only measure of fatigue, but more recent experimenters are convinced that the decrement in work output is not, by itself, a valid measure of fatigue because of the psychological factors involved. In this connection, Bartley and Chute (4) say, "Under many circumstances motivation will by pass both fatigue and impairment and give increased production." These references indicate the disagreement which exists concerning physiological impairment and fatigue. In this research only physiological impairment in the muscles under investigation will be considered.

The physiological impairment in the muscles must, then, be removed by a rest period for the worker. The fact that rest periods are required throughout the day's work is certainly not new. Ryan (5) says,

> The basic question in a discussion of rest periods in industry does not involve a choice between the presence or absence of rest periods. The studies by Vernon and others indicate clearly that some form of rest period is taken by the worker even where there is no formal plan allowing them. The problem consists rather of determining whether or not a formally authorized rest period is more effective than an unauthorized rest, and if so, what program of rest is most beneficial.

Taylor (6) in some of his first investigations discovered that

> When pig iron is being handled (each pig weighing 92 pounds), a first class workman can only be under load 43% of the day. He must be entirely free from load during 57% of the day. And as the load becomes lighter, the percentage of the day under which the man can remain under load increases.

Through empirical data Taylor was able to arrive at these percentages but had no comment on how the work-rest cycle was to be established to accomplish the percentages.

Since Taylor's time much thought and experiment has been devoted to determining the optimum work-rest cycle. Most of the experiments, however, have established arbitrary work and rest cycle on an intuitive basis with no particular concern for individual physiological differences among workers. There have also been few studies conducted measuring the validity of these arbitrary rest periods according to a physiological criterion.

The following paragraph from Ryan (7) may shed some light on the rest period problem,

> As in the case of hours of work, the principle criteria of the value of rest periods have been hourly rate and total output per day. The results of introducing regular rest periods vary from slight increases in hourly rate which are insufficient to offset the time lost in the period, to increases which are sufficient to increase the <u>total</u> output by substantial amounts. There are enough data to warrant the conclusion that nothing is lost by the use of regular rest periods, and considerable gain in output and "morale" may result. It is to be expected that some arrangements of rest periods would be more effective than others, but there have been few experiments in which the schedule of rest periods has been varied systematically in an industrial setting. This is understandable when we consider that it may take a long time for the full effects of the rest periods to be reliably established.

A study by Vernon (8) showed that men on heavy work rested one-half to one-fourth of the working time. Shepard (9) reports investigations of workers on medium-heavy muscular work and on an 8-hour day which show that the worker cannot give his maximum output unless he rests approximately 15% of the time during the working. It is interesting that in these studies the work load was virtually the same, yet the results show a variation of from 15% to 53% of the working time for rest period.

Other studies (10) have shown that a given amount of time used for rest periods is more effective if the rests were brief and frequent than if long and infrequent.

The physiological approach to work measurement has been encouraging. The constant motivation for continuing investigations in the measurement of work through physiological cost parameters is based on the subjectivity of allowances in the standard Industrial Engineering tools, such as motion and time study, Activity Analysis, Predetermined times, etc., which are being used to establish the amount of work which a worker does. It is hoped that in the future physiological variables can be made operational to accompany their inherent objectivity so that the physiological cost may be an accurate predictor of the amount of physical work being done by a worker.

To date, research has been conducted by many different investigators on physiological factors such as oxygen consumption, heart sound, heart rate and heart rate recovery, galvanic skin response, pulse rate, and blood pressure in an effort to find an operational predictor for the physiological cost of work. Presently, the most promising of these predictors is the oxygen consumption method used at the Max-Plank-Institut fur Arbeitsphysiologie; and the heart rate recovery and others studied by Brouha (11) (12) (13) at the Haskell Laboratory of the E. I. du Pont Company.

Another physiological variable which shows promise as a predictor of physiological cost of work is the electrical potential in the muscles. This potential can be measured by electromyographic techniques and this measure usually varies according to the amount of physical or mental work which an individual is doing. The EMG seems especially valuable for measuring work of the limbs, since this amount of work is frequently too small to be detected by heart rate recovery, oxygen consumption, or the other large scale predictors. Williams (14) says,

> Inherent variations in the workings of the human body under physiological investigations of small differences in method and work rate are difficult, except possibly in certain critical regions. In many important cases in practice involving small muscles such as those of the hand and fingers the field methods of measuring heart rate and heart energy output are not considered practical as discriminating tools.

The EMG has been used frequently in both psychological and physiological fields. A valuable publication for a new researcher using electromyography is the Manual of Surface Electromyography (15), which is a comprehensive handbook of techniques and methods of electromyography. Psychologists have used the EMG in studying muscle action potentials in subjects undergoing various types of mental activity and interesting results have been obtained. Physiologists, as well, have conducted studies in electromyography in connection with the physical tension in the muscles and other physical effects on the body.

Probably the most important single result in EMG studies of muscle action potentials is the evidence that the potentials are a good indicator of the tension in the muscle. Inman, et al. (16) investigated muscular tensions and lengths in cineplastic amputees by measuring them with a strain-gage dynomometer and simultaneous MAP's were recorded over and in the muscles. The result showed that the intergrated MAP parallels tension in human muscles contracting isometrically. No quantitative relationship exists when a muscle is allowed to change in length, or between MAP amplitude and muscle force. The MAP amplitude diminishes when muscles are stretched.

Wilcott and Beenken (17) in a study designed to supplement the study by Inman, et al. also tested subjects on a dynomometer in an effort to find a quantitative relationship between the amount of muscular tension and the integrated MAPs. The results showed an essentially linear relationship between the force of muscle pull and the integrated MAPs for females and a slightly curvilinear relationship for males, but for the practical range usually considered in day to day activity both relationships could be considered linear. Another interesting result of their study is that equal magnitudes of muscle action potentials do not always indicate equal magnitudes of muscle tension. Lippold (18) also discovered the linear relationship existing between muscle tension and the integrated MAPs.

Davis (19) studied the age pattern of muscle activity by studying the muscle potentials of adults vs. 9-year old children in a weight lifting task. The results were that the "rest" level in children is much higher than the "rest level" in adults. Davis also finds that for equal amounts of physical work the size of the action potential varies inversely with the cross-section area of the individual muscle and that the action potential increases for children is always greater than that for adults. These are very important results in considering the use of the level of the muscle action potential as a quantitative indicator of work done by an individual because they imply that the level of muscle action potentials is not valid for this purpose. This leds to the possibility that another parameter, such as change of the muscle action potential, may be a valid indicator of work being done.

Forrest (20) investigated the influence of the length of task on rate of work and level of muscular tension and confirmed the hypothesis that the more difficult the work the higher the muscle tenseness, and also the longer the task the more tenseness because the increased length implies to the mind increased difficulty. Duffy (21) investigated the relationship between muscular tension and quality of performance, and arrived at the conclusions that poor performance is accompanied by high tension while good performance is accompanied by a range of tension from low to high but usually low or moderate.

Many studies of muscle action potentials are primarily psychological in nature, indicating the importance of adequate psychological preparation of the subjects for conducting physiological experiments. Surwillo (22) studied MAP gradients which are defined as the progressive increase in electrical activity, in certain muscles from the beginning to the end of a task. He discovered that subjects with higher incentives had steeper gradients when performing a task. Bartoshuk (23) also investigated MAP gradients as an indication of motivation. The results of his study indicated that the MAP gradient slope is a direct function of the strength of motivation.

Electromyography has also been used in the study of fatigue in the muscles. Knowlton, _et al_. (24) made observations on control muscles during work to subjective fatigue with several loads at several work rates in an attempt to find the relation of load and work rate to fatigue. The task was to lift a hand weight at a given rate to the point of subjective fatigue. The conclusions of this comprehensive study were that the amplitude of the EMG shows a progressive increase from the initial to the final contraction of control muscles carrying moderate loads to subjective fatigue; and that the rate and extent, but not the direction, of this voltage change is altered by changes in load and work rate at maximum voltage.

Lippold, et al. (25) also studied the electromyography of fatigue. Changes in the electrical activity of muscles during and following fatigue were investigated and two types of fatigue were considered: (1) fatigue following short, strong contractions, and (2) fatigue following constant tension over a long length of time. The results of the experiments using calf, arm and finger muscles, show that as voluntary contraction progresses the electrical activity recorded from the muscle increases, substantiating previous studies. Also for constant tension, held for several minutes, the action potential spikes become closer together and the amplitude is increased. Also shown is that the size and form of the action potential changes in that the peak to peak amplitude is decreased while the duration is lengthened.

In general, electromyography appears to be a useful tool for laboratory analysis of muscle action potentials under various psychological and physiological conditions. For this research it is hypothesized that for the work-rest periods investigated, the EMG response will provide a quantitative indication of the physiological cost of the total work being done by the subjects. Four subjects will be tested at arbitrary levels of work output, measured by an ergometer; and at arbitrary lengths of rest periods, the length of the rest period being a fixed percentage of the time worked for each trial. At the same time, the electrical potential in the forearm muscles being investigated will be measured using an electromyograph. Total work output data, rest period data, and physiological cost data, as measured by the electromyograph, will be analyzed. An attempt will be made to correlate the total work done, the length of the rest periods, and the electromyograph response using appropriate analysis in an effort to determine if an optimum work-rest cycle exists such that the physiological cost to the worker is minimized.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

The following instrumentation and equipment was used in this experimentation: (1) Electroencephalograph/Electrocardiograph preamplifier; (2) Electrocardiograph preamplifier, power amplifier and power supply; (3) Recorder; (4) Surface electrodes; (5) Hand ergometer; (6) Miscellaneous equipment. The combination of electroencephalograph/electrocardiograph preamplifier; electrocardiograph preamplifier, power amplifier and power supply, recorder, and surface electrodes comprise the electromyograph.

Electroencephalograph/Electrocardiograph Preamplifier.--A Sanborn model 55 EEG/ECG preamplifier (Figure 1) was utilized as the initial preamplifier for the MAP's received from the arm of the subject. An input is provided for this unit from the 3 electrodes placed on the subject and an output to transmit the amplified MAP's to the ECG preamplifier. Controls are provided on this unit for attenuating the input signal in the ratios of 50, 25, 10, 5, 2.5, and 1; and also for modifying the high and low frequency portions of the input signal. The power for this unit is supplied by self-contained 6.5 volt mercury batteries.

Electrocardiograph Preamplifier, Power Amplifier, and Power Supply.--A Sanborn model 150-1600 ECG preamplifier was used with a basic Sanborn model 150-200B/400 power amplifier and power supply (Figure 3). The

ECG preamplifier received the output signal from the EEG/ECG preamplifier and transmitted the signal to the recorder through the power amplifier. The ECG preamplifier size contained an attenuation control, thus it was possible to control the attenuation ratios by either the EEG/ECG preamplifier or the ECG preamplifier.

Recorder.--The recorder used was a Sanborn model 154-100B four channel recorder fitted into the power amplifier and power supply chassis (Figure 3). The recording arms were hot-wire ribbons driven by galvanometers. Each galvanometer movement caused a movement of the writing arms which burned a trace on black Sanborn Permapaper recording tape as the tape moves at a constant selected speed over a knife edge writing platen under the hot-wire ribbon. This resulted in a record which was instantaneous and permanent. Only one of the four available channels was used in this research.

Surface Electrodes.--The two electrodes used to detect the MAP's in the subjects were stainless steel metal, 5 mm diameter soldered to Belden Number 8014 wire. These wires were then attached to standard leads provided with the EEG/ECG unit. The ground electrode used was 25 mm diameter stainless steel metal and was attached to a standard lead provided with the EEG/ECG unit.

Hand Ergometer.--A specially designed hand ergometer (Figure 2) was used to provide a task whereby the amount of work which the subjects were doing could be controlled and measured. The ergometer consisted of two vertical handles, the rear handle being stationary and the front handle free to move on rollers in the horizontal plane. The front handle was attached to weights by a cord which extended horizontally over a pully. The subjects work task consisted of gripping the handles, thus moving the weight at the opposite end of the cord. The hand ergometer was attached to a table, specially constructed for right handed subjects, and adjustable to different heights to insure comfort while operating the ergometer.

Miscellaneous Equipment.--Miscellaneous equipment used was: (1) A Meylan model 208A Stop Watch to time the work and rest periods for each trial; (2) A Simpson model 260, series III, Volt-Ohm-Milliammeter to test the electrical resistance of the subjects skin in preparation for each trial (Figure 1) (3) A Franz electric metronone to provide the subjects with a visual and aural beat so they could work at a constant given rate (Figure 2) (4) Other miscellaneous equipment used in attaching the electrodes to the subjects, such as adhesive tape, band aids, rubber straps, cellulose sponges, electrode paste mixed from a formula given by Davis (26), and a skin-cleaning solution of ether and acetone given by Davis (27).

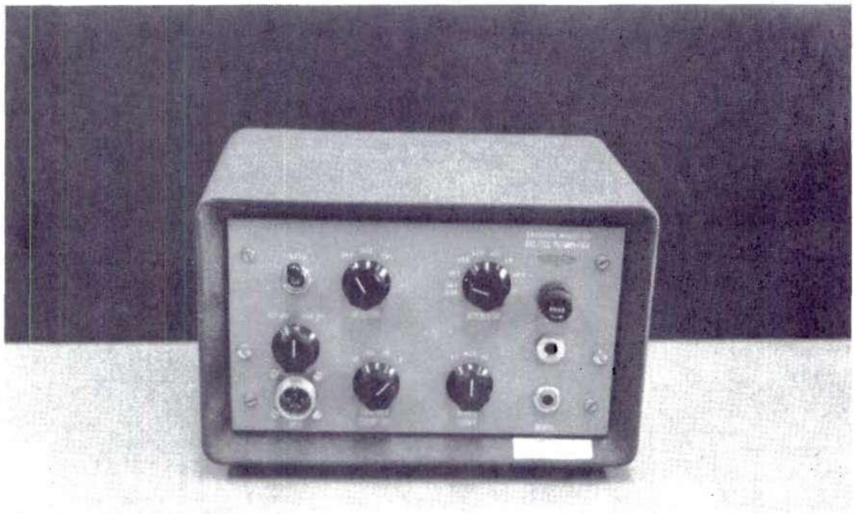

Figure 1. EEG/ECG Preamplifier

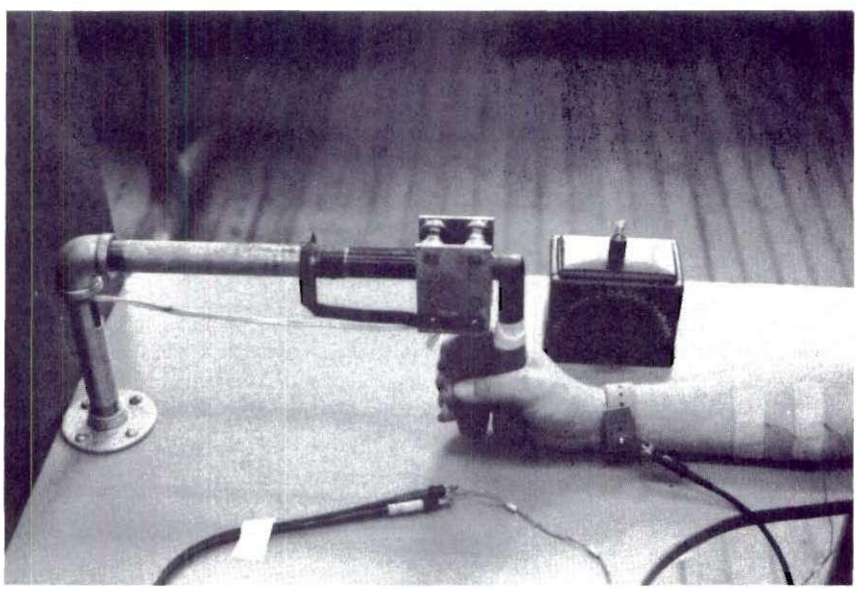

Figure 2. Hand Ergometer and Metronone

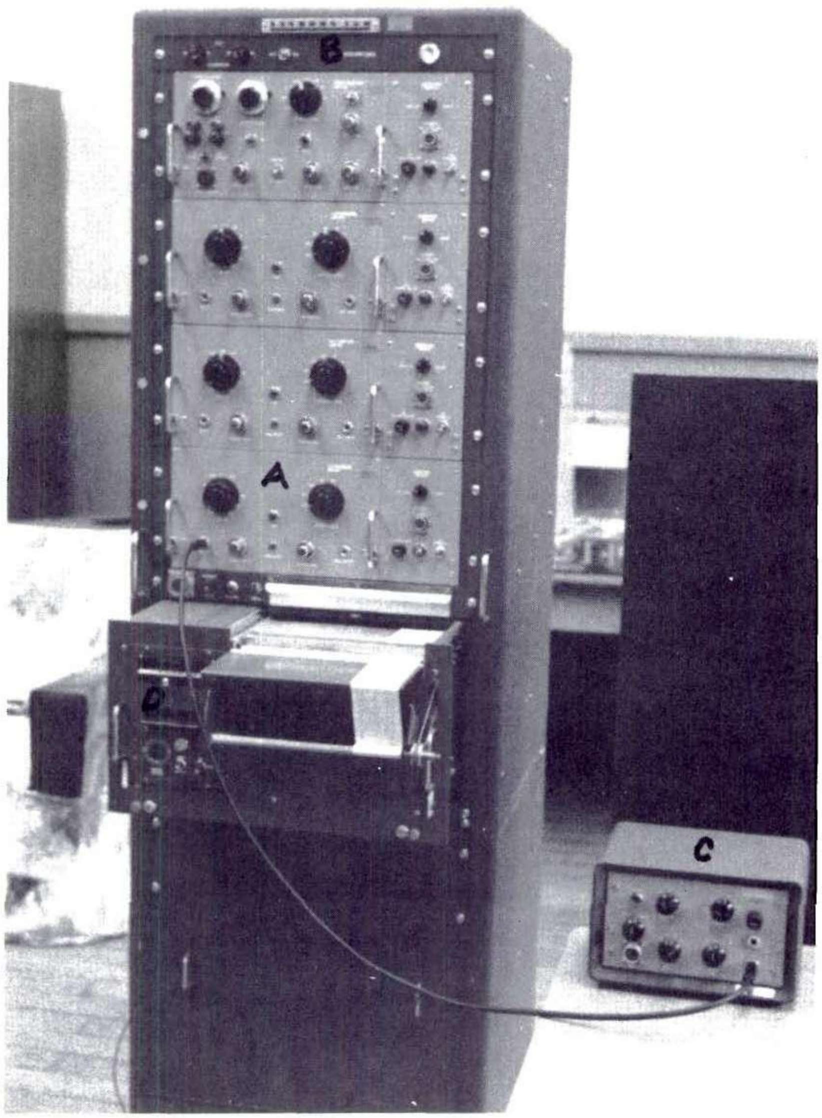

Figure 3. Basic Recording Apparatus

A. ECG Preamplifier
B. Power Amplifier and Power Supply
C. EEG/ECG Preamplifier
D. Recorder

CHAPTER III

EXPERIMENTAL PROCEDURE

Information concerning the subjects, tasks, environment in which the experiments were conducted, the variables investigated, and the design of the experiment will be discussed in this chapter.

Subjects.--The four subjects for this research were selected from a population of graduate students in the Industrial Engineering Department of the Georgia Institute of Technology. Subjects were selected according to their willingness to participate and their availability, and no financial compensation was used. The following table indicates concomitant physical data concerning the subjects.

Table 1. Subject Concomitant Data

Subject	Age	Height	Weight	Distance Weight Moved
1	28	5'6"	145#	0.75"
2	25	5'10"	155#	1.375"
3	27	5'7"	145#	1.375"
4	23	5'11"	185#	1.25"

The subjects were all right-handed and assumed to be in average general physical condition; however, no physical tests were administered to the subjects.

Tasks.--One standard task was performed by each subject. The standard task was that the subjects were required to open and close their right hand grip on the ergometer handles at a given constant rate. The limit of the opening movement was the point where the subject could maintain control of the forward handle with his fingers without additional movement of the hand or arm, and the limit of the closing movement was the point where the two handles were touching without additional pressure being applied by the fingers or hand. The rate used was one complete gripping action per second and was maintained by the use of the metronone which was set at one beat per second. Since the distance the weight was moved was slightly different for each subject, the total work done was also slightly different for each subject. The work done was calculated by the following formula:

$$W = T\,D\,C$$

where: W = total work in inch-pounds

T = total time worked in minutes

D = distance weight moved in inches

C = constant = 120 pounds per minute

The average amount of work for each work-rest trial was then calculated as the average value of the work done by the four subjects for each work-rest trial.

For each trial the subject was required to work at the constant given rate for given lengths of work and rest periods. The EMG data were recorded only during the work periods. The total length of each trial was thirty minutes with a one minute rest period preceding the initial work period. Figure 4 shows a typical work rest cycle.

Figure 4. Typical Work-Rest Cycle

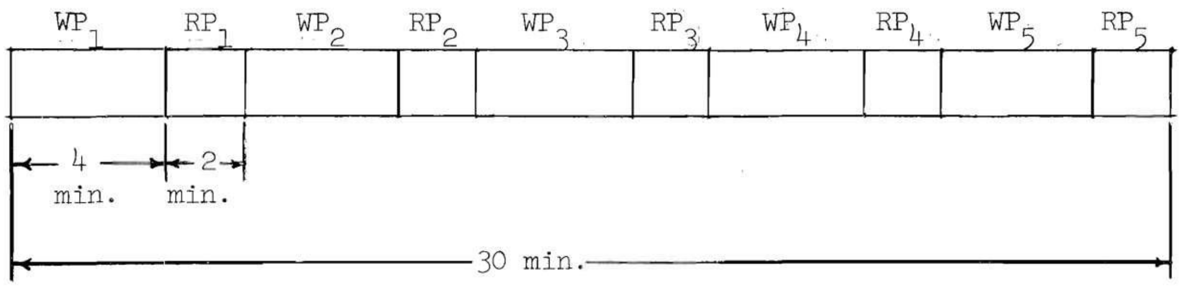

Table 2 shows all the combinations of work and rest cycles based on four minutes work equals the one hundred per cent work level.

Table 2. Combinations of Work-Rest Periods Tested

Trial	Work Level (%)	Rest Level (% of Work Level)	Work Period (Min.)	Rest Period (Min.)
1	100	25	4	1.0
2	100	50	4	2.0
3	100	75	4	3.0
4	75	25	3	0.75
5	75	50	3	1.5
6	75	75	3	2.25
7	50	25	2	0.5
8	50	50	2	1.0
9	50	75	2	1.5

Each subject was tested one time at each combination of work and rest period. The only arbitrary limitation imposed on the timing of trials was that there must be a minimum of four hours between trials to allow for recovery of the muscles.

Figure 5 illustrates the analysis of variance experimental design utilized in the analysis of the data.

Figure 5. Experimental Design

		R_1	R_2	R_3
S_1	W_1			
	W_2			
	W_3			
S_2	W_1			
	W_2			
	W_3			
S_3	W_1			
	W_2			
	W_3			
S_4	W_1			
	W_2			
	W_3			

where:

S_i = Subjects ($i = 1,2,3,4$)

R_j = Rest Periods ($j = 1,2,3$)

W_k = Work Periods ($k = 1,2,3$)

Concomitant Variables.--The uncontrolled environmental concomitant variables were temperature and humidity which were not recorded. The experiment was conducted during the month of April, 1961. Subject concomitant variables (Table 1) were recorded but no attempt at analysis is made in this research. The time of day at which the experiments were conducted depended on the schedules of the subjects and was between the hours of 8:30 A.M. and 10:30 P.M.

Experimental Environment.--The laboratory for this experimentation, the same as used by Schwartz (28) and Hall (29), was a typical classroom in the Industrial Engineering building at Georgia Institute of Technology. The dimensions of the room were 20 feet by 30 feet and the color of the room was green, the upper portion being light green and the lower portion dark green. A large double door provided the entrance to the room and was kept closed during the experimentation to avoid distraction of the subject. Windows and transoms provided ventilation during the experiments and the ergometer table faced the wall thus keeping direct sunlight out of the subjects eyes. Lighting was provided by overhead flourescent lamps and the noise level was slightly less than in a normal classroom since classes were being conducted in adjacent rooms.

Procedure.--Since each subject followed the same experimental procedure a description of the procedure followed by only one subject will be necessary. The subjects were all informed prior to the first experiment on the procedure and purpose of the experiment but they were not given any information concerning the expected results. They were all instructed that, although some experiments would be physically more difficult than others, all of the experiments were within their capabilities, a fact which had been established by preliminary testing. They were not told what combination of work and rest period they would be accomplishing on each trial. The order of the trials was randomized to minimize conditioning or learning effects.

The subjects reported to the laboratory on a prearranged schedule and were seated comfortably at the ergometer table. The arrangement of the experiment area is similar to that shown in Figure 6. A large masonite board was attached to the table between the subject and the experimenter so that the subject would not be distracted or influenced by the experimenter's activity.

When the subject was seated comfortably the surface electrodes were attached over the forearm flexor muscles on the right arm. The actual method of attaching the electrodes was developed by experimentation in the laboratory; therefore, it will be described in detail. Initial preparation for the placement of the electrodes included cutting two pieces of 1" adhesive tape to form 1" squares. In the center of these pieces of tape a hole was cut approximately 5 mm diameter. Also prepared were two strips of adhesive tape approximately 3 inches long and 1/16" wide.

The subject's skin was then prepared by vigorous and thorough scrubbing of the electrode placement area on the forearm and wrist with cotton saturated with a solution of 50% ether and 50% acetone. Forearm electrode placement techniques were as recommended by Davis (30). First the subject placed his forearm on the table, palm up, and measurements

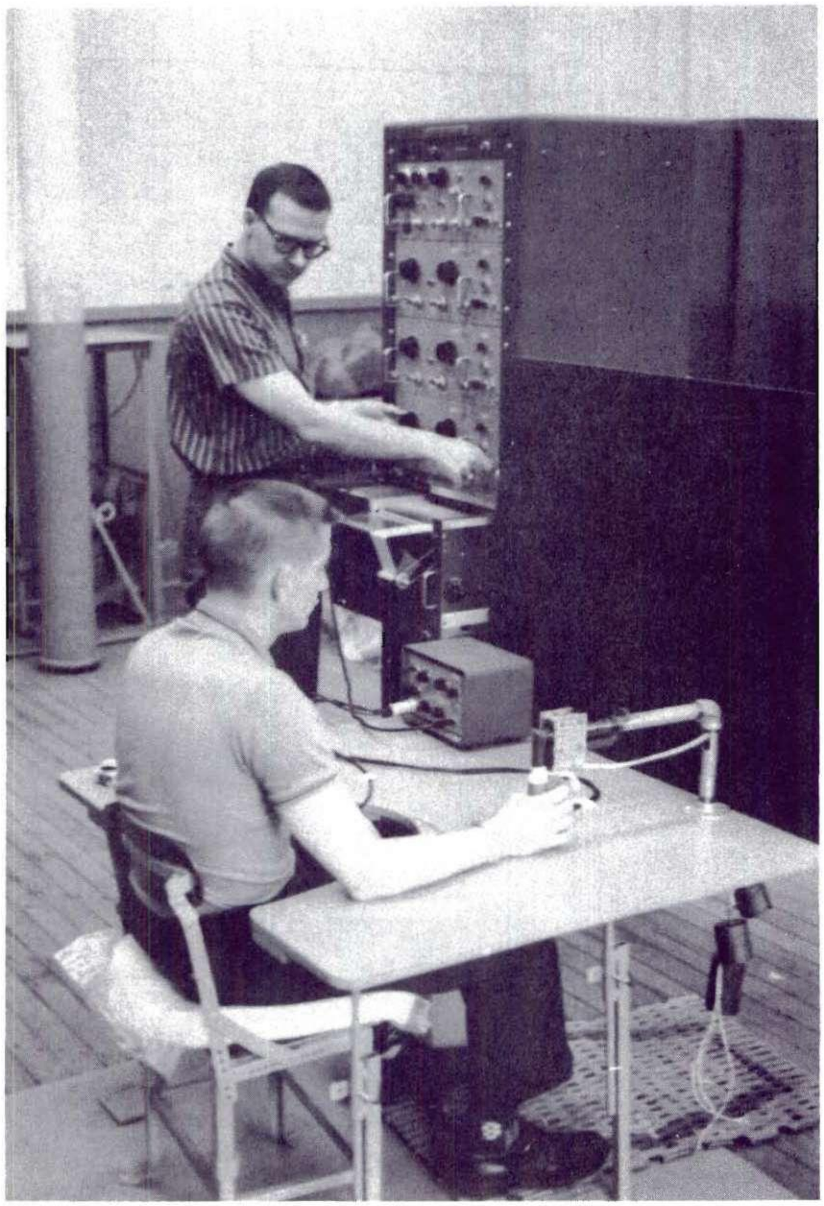

Figure 6. Experimental Area

were made along a line from the elbow to the thumb; i.e., from the medial humeral epicondyle to the styloid process of the radius (Figure 7). The first electrode placement point was located at the point one-third of the way from the elbow on the line. The second electrode point was placed on the same reference line at a point two inches from the first electrode point in the direction toward the thumb.

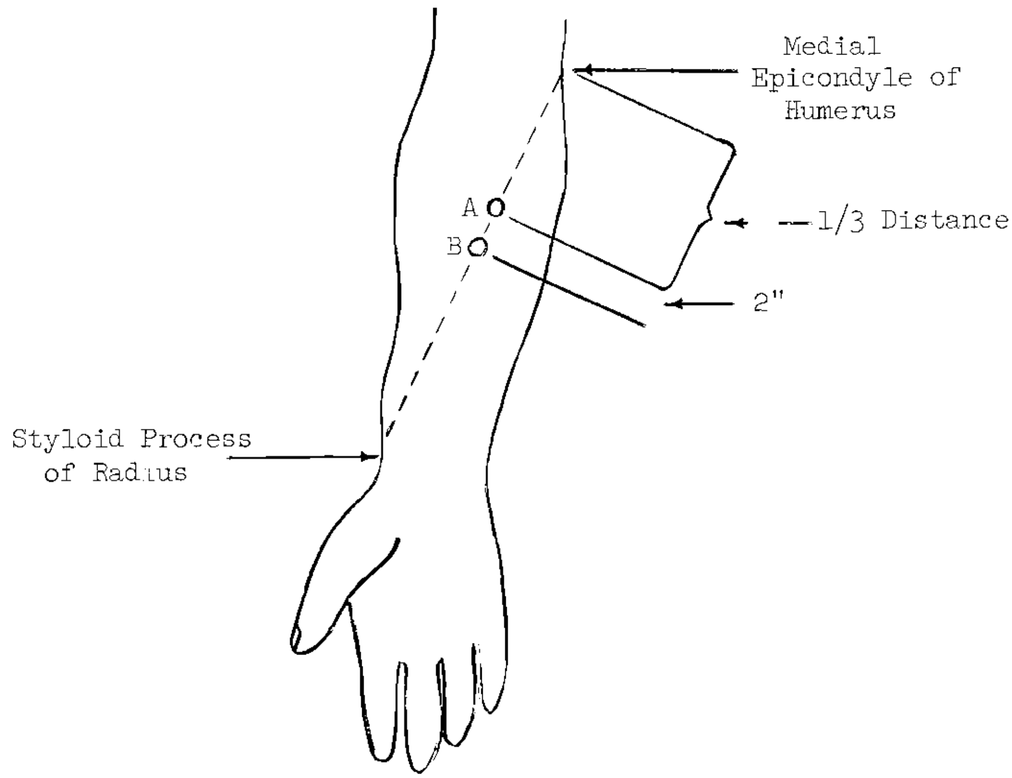

Figure 7. Standard Forearm Flexor Electrode Placement Points

A. First Electrode Placement Point

B. Second Electrode Placement Point

After locating the placement points the two pieces of 1" square adhesive tape were placed over the points and fastened to the skin such that the placement points on the skin were in the centers of the holes in the tapes. Electrode paste was then massaged thoroughly into the areas of the skin exposed by the holes in the tape and the skin resistance was tested with an ohm meter to determine if the conductivity was in the acceptable resistance range of 5,000 to 30,000 ohms (Figure 8).

The surface electrodes were then rubbed with electrode paste and placed next to the skin in the holes in the tape over the placement points and "tacked" into place by the 3" x 1/16" strips of adhesive tape. Two cellulose sponges, 1/4"x1/4"x1/10", saturated with electrode paste were then placed directly over the electrodes and two 1" band aids were then firmly attached over the sponges and to the skin thus providing a firm and reliable contact for the MAP electrodes (Figure 8). The small voltages involved in MAPs required careful control of electrode placement to insure reliable data.

The ground electrode was then placed on the wrist with a rubber strap after massaging the skin and the electrode with electrode paste (Figure 8).

After electrode placement, the EMG was checked for proper operation and the metronone was actuated and placed within sight and sound of the subject. A preliminary check was made of the subject's response prior to each trial. The attenuation level was adjusted according to the particular subject and trial, and the recording tape travel speed was set at 2.5 mm per second. The subject was then instructed to rest at the work station (Figure 9) for one minute and verbal signals were given to begin and end the work and rest periods thereafter.

At the completion of the experiment the electrodes were removed

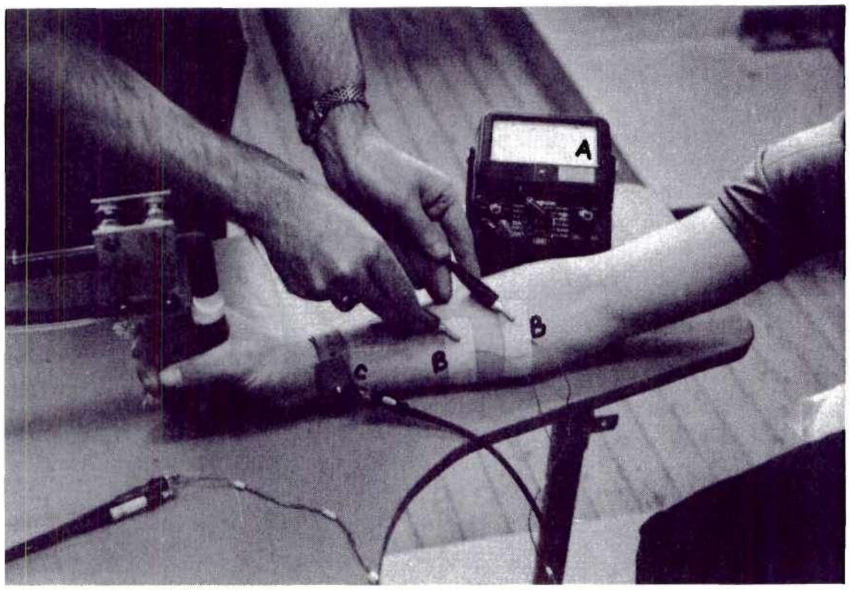

Figure 8. Testing Skin Resistance

A. Ohmmeter

B. MAP Electrodes

C. Ground Electrode

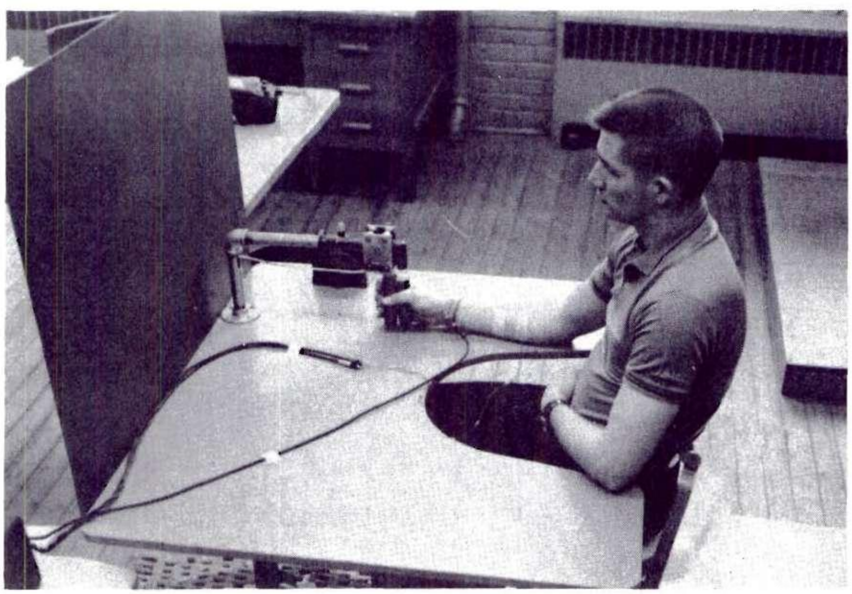

Figure 9. Subject Prepared for Experiment

from the subject and the forearm cleansed of the electrode paste. This procedure was used for each subject on each of the nine different work-rest cycles.

CHAPTER IV

ANALYSIS AND RESULTS

The experimental design used in this research was a three-factor factorial design with the main sources of variation being subjects, work periods, and rest periods, with the dependent variable of muscle action potentials.

The EMG data verified the expectation that for each contraction of the subject's grip, i.e. work done to lift the weight, produced an increased electrical voltage response (Figure 10). These voltage variations are a measure of muscle action potentials and may be correlated with physiological cost. They were analyzed by considering the average values of the peak-to-peak amplitude, measured in mm, for three samples of each work period. The three samples considered were the start of the work period, middle of the work period, and end of the work period. At rest data were not treated in this experiment.

The average values for the "start" and "end" samples were obtained by first eliminating the initial and final ten increased voltages in each work period to avoid any error of acclimation or anticipation of the end of the work period effects. Then the twenty increased voltages following the initial ten and the twenty increased voltages preceding the final ten were measured and averaged. These averages were considered a representative sample on the initial and final voltage responses for each work period. For the "middle" sample, twenty increased voltages in the center of each work

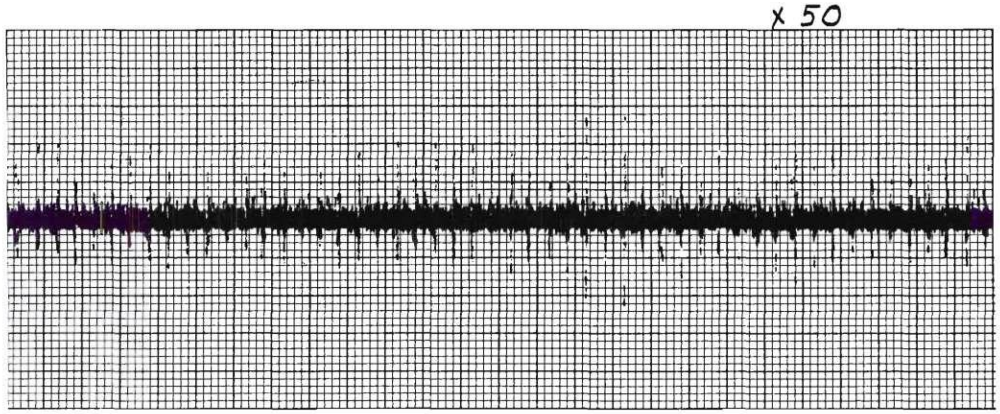

Figure 10. Muscle Action Potential Recording Tape

period were averaged. It was decided that the average middle sample of the voltage responses would be most representative of the electrical potential measurement during the work period. The dependent variable data for the analysis of variance was the average of the middle samples of the work periods for each combination of work period, rest period and subject was used.

Table 5 shows the general form of the three-factor experimental design (31), and Table 6 shows the complete analysis of variance, including the coded mean squares.

Since the mean square values of variation between subjects, rest periods, subjects x rest periods interaction, and rest periods x subjects interaction are all less than the error (residual) mean square these sources may be considered nonsignificant and may be pooled with the residual to form a new residual (Table 3).

Table 3. Revised Analysis of Variance Table

Source	d. f.	S.S.	M.S.
W	2	28,686.22	14,343.11
W x R	4	28,984.20	7,246.05
Residual	29	128,385.47	4,427.08
Total	35	186,055.89	

The work periods x rest periods interaction was then tested for significance. Table 4 shows the degrees of freedom, F-test ratios, and the 10% and 5% level of significance values (32).

Table 4. Test for W x R Interaction

Source	d f.	F-Ratio	10% Level of Significance	5% Level of Significance
W x R	4/29	$\frac{7,246.05}{4,427.08} = 1.637$	2.15	2.70
Residual				

Since Table 4 shows the work periods x rest periods interaction is not significant at the 10% level of significance it may also be pooled with the residual to form a new residual to test for the significance of the work periods. Table 7 shows the degrees of freedom, F-test ratios, and the 10% and 5% level of significance values.

Table 7 shows that the work periods variation is significant at the 10% level of significance but not at the 5% level of significance.

Results.--It was observed that there was no significant variation between subjects or rest periods; and no significant interaction between subjects and work periods, work periods and rest periods, or rest periods and subjects. From table 7 it can be seen that the work periods variation is significant at the 10% level of significance, but only after all the other main effects and interactions have been pooled into the residual, giving the work periods a greater opportunity to become significant.

No significant interactions are desired in order that the most information may be gained from the variation of the main effects; however,

Table 5. General Three-Factor Experimental Design

Source	Degrees of Freedom	Sums of Squares	Expected Mean Squares
S	(I-1)	$\sum_{i=1}^{I} T_{i}^2{\cdot\cdot}/9 - T^2{\cdots}/36$	$wr\sigma_s^2 + w\sigma_{sr}^2 + r\sigma_{sw}^2 + \sigma_o^2$
W	(K-1)	$\sum_{k=1}^{K} T^2_{..k}/12 - T^2_{...}/36$	$sr\sigma_w^2 + s\sigma_{wr}^2 + r\sigma_{ws}^2 + \sigma_o^2$
R	(J-1)	$\sum_{j=1}^{J} T^2_{.j.}/12 - T^2_{...}/36$	$ws\sigma_r^2 + w\sigma_{sr}^2 + s\sigma_{wr}^2 + \sigma_o^2$
S x W	(J-1)(K-1)	$\sum_{i=1}^{I}\sum_{k=1}^{K} T^2_{i.k}/3 - \sum_{i=1}^{I} T^2_{i..}/9 - \sum_{k=1}^{K} T^2_{..k}/12 + T^2_{...}/36$	$r\sigma^2_{ws} + \sigma_o^2$
W x R	(K-1)(J-1)	$\sum_{j=1}^{J}\sum_{k=1}^{K} T^2_{.jk}/4 - \sum_{j=1}^{J} T^2_{.j.}/12 - \sum_{k=1}^{K} T^2_{..k}/12 + T^2_{...}/36$	$s\sigma^2_{rs} + \sigma_o^2$
R x S	(J-1)(K-1)	$\sum_{i=1}^{I}\sum_{j=1}^{J} T^2_{ij.}/3 - \sum_{i=1}^{I} T^2_{i..}/9 - \sum_{j=1}^{J} T^2_{.j.}/12 + T^2_{...}/36$	$w\sigma^2_{rs} + \sigma_o^2$
RESIDUAL	(I-1)(J-1)(K-1)	$\sum_{ijk} X^2_{ijk} + \sum_{i=1}^{I} T^2_{i..}/9 + \sum_{j=1}^{J} T^2_{.j.}/12 + \sum_{k=1}^{K} T^2_{..k}/12 + \sum_{i=1}^{I}\sum_{j=1}^{J} T^2_{ij.}/3$ $\sum_{i=1}^{I}\sum_{k=1}^{K} T^2_{i.k}/3 + \sum_{j=1}^{J}\sum_{k=1}^{K} T^2_{.jk}/4 - T^2_{...}/36$	σ_o^2
TOTAL	(IJK) - 1	$\sum_{ijk} X^2_{ijk} - T^2_{...}/36$	

Table 6. Analysis of Variance Table

Source	Degrees of Freedom	Sums of Squares	Mean Squares
S	3	12,332.11	4,110.70
W	2	28,686.22	14,343.11
R	2	867.72	434.86
S x W	6	31,010.23	5,168.37
W x R	4	28,984.20	7,246.05
R x S	6	14,577.92	2,429.65
RESIDUAL	12	69,597.49	5,799.79
TOTAL	35	186,055.89	

Table 7. Test for W Variation

Source	d.f.	F-Ratio	10% Level of Significance	5% Level of Significance
W	2/33	$\frac{14,343.11}{4,768.78} = 3.00$	2.48	3.29
Residual				

it was expected that some interaction would be present between the subjects and rest periods and the subjects and work periods because of the physiological differences between subjects. It is possible that the work periods and rest periods selected were at a threshold where the subjects were capable of accomplishing the tasks without significantly measurable impairment, which could explain this lack of interaction. Significant interaction was expected between work periods and rest periods since the rest periods were chosen as a percentage of the work periods. It is possible that the random error in the experiment was so large as to cause the interactions to be insignificant.

The absence of significant variation between rest periods might indicate that the selected rest period differences' were not great enough to cause detectable variation in MAPs, or that random error was large enough that the significance between rest periods was lost.

The lack of variation between subjects was an unexpected result, i.e., it was expected that variation between subjects would be significant (33). It is felt that random error obscured this relationship.

It is interesting that variation between work periods was not significant in the original analysis (Table 6), but became significant after the pooling of the other sources of variation provided enough degrees of freedom in the residual for it to do so. Work period significance, considering the apparently large random error in the experiment, is encouraging.

In an effort to identify possible sources for the random error, two parameters were investigated. These parameters were variation within subjects and variation in final MAP samples for the three work levels. Figures

11, 12, 13, and 14, show the average value of the MAP for the work periods in each trial for each subject. It is apparent from these figures that variation exists within each subject for different trials. Figure 15 shows the MAP samples at the completion of the three levels of work done (expressed as time worked). The purpose of this analysis was to investigate a possible relationship between the physiological cost of the three levels of work; however, the figure indicates that there is no significant trend in MAP for the three work levels.

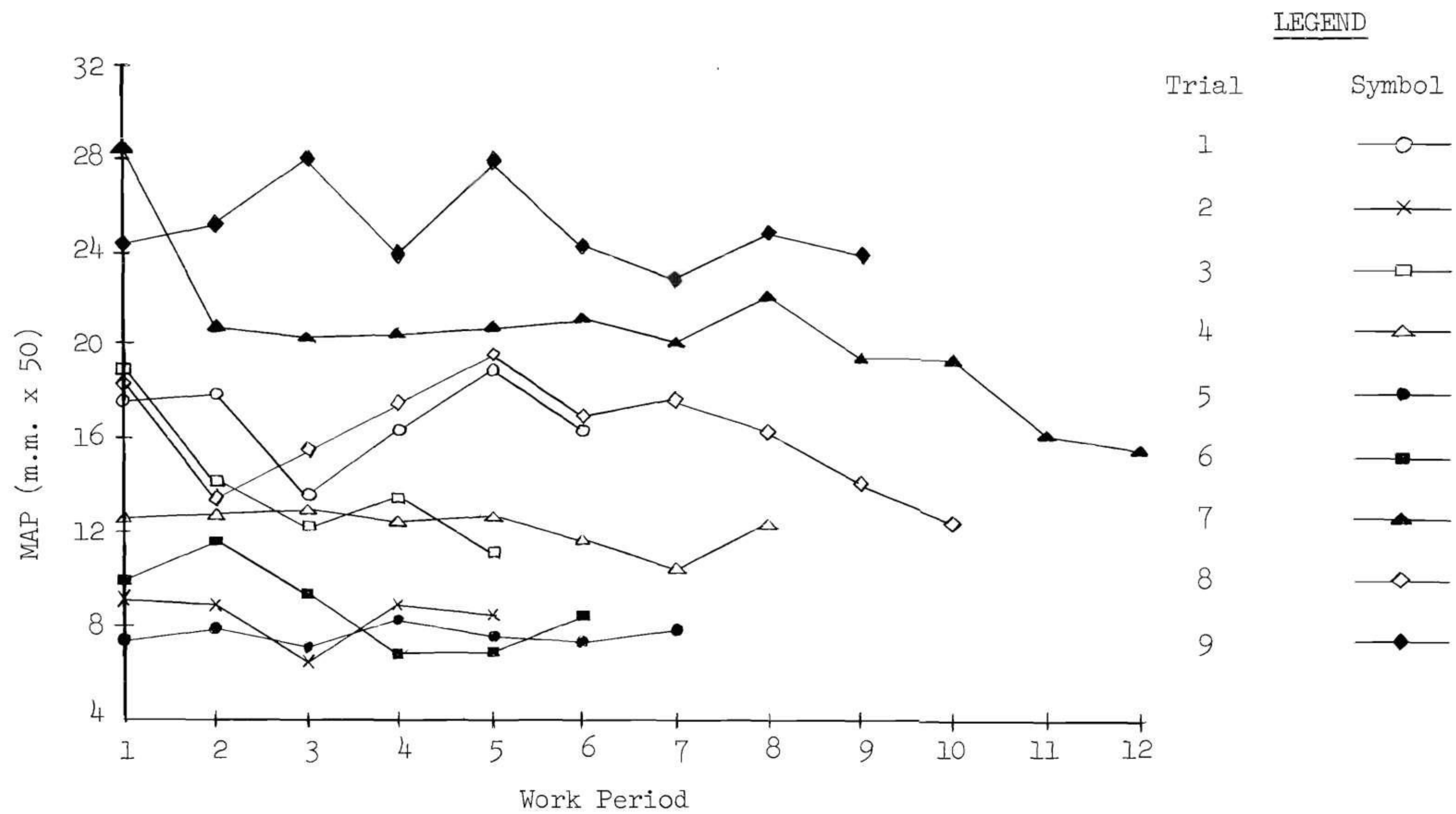

Figure 11. Average Work Period MAP for each Trial - Subject No. 1

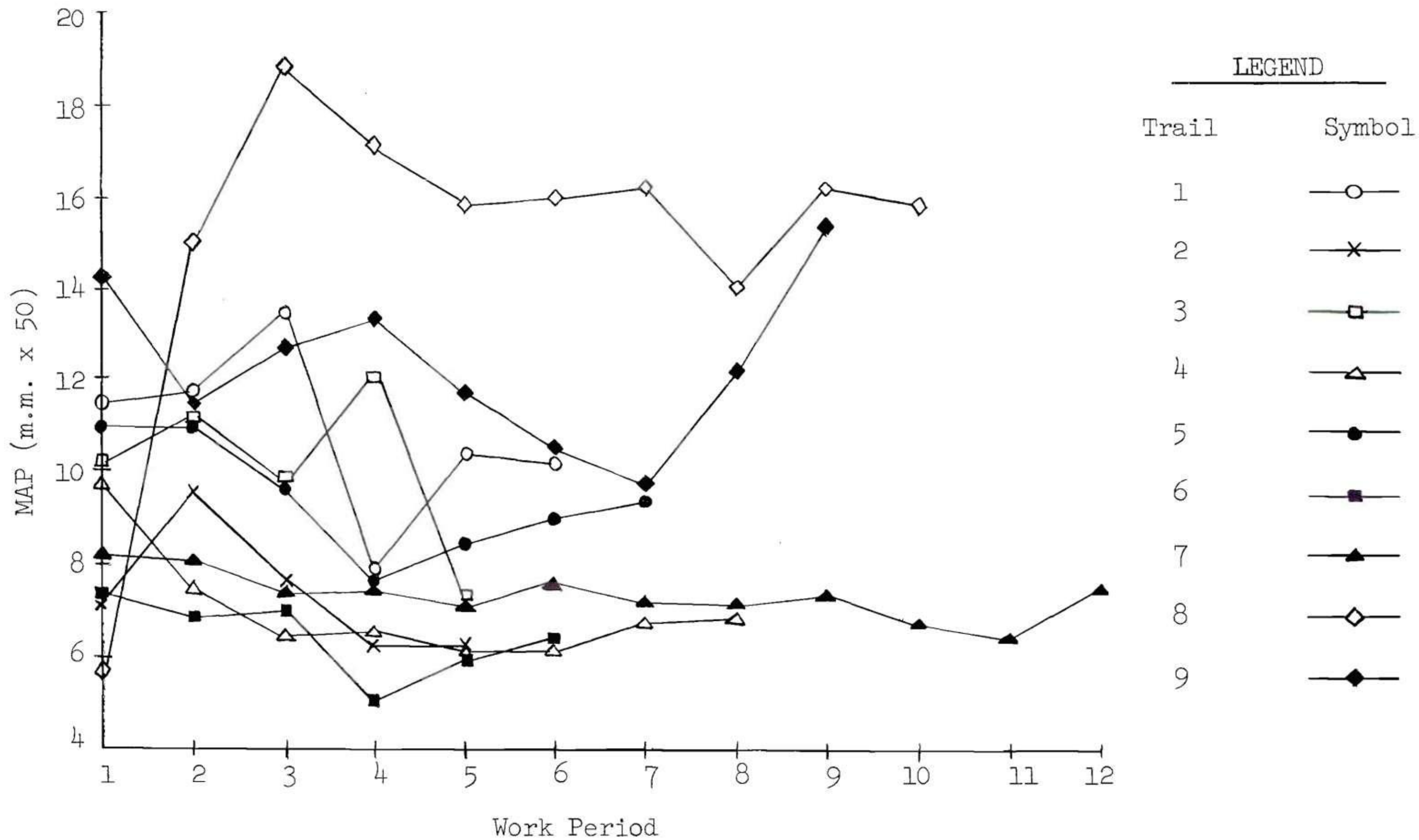

Figure 12. Average Work Period MAP for each Trail - Subject No. 2

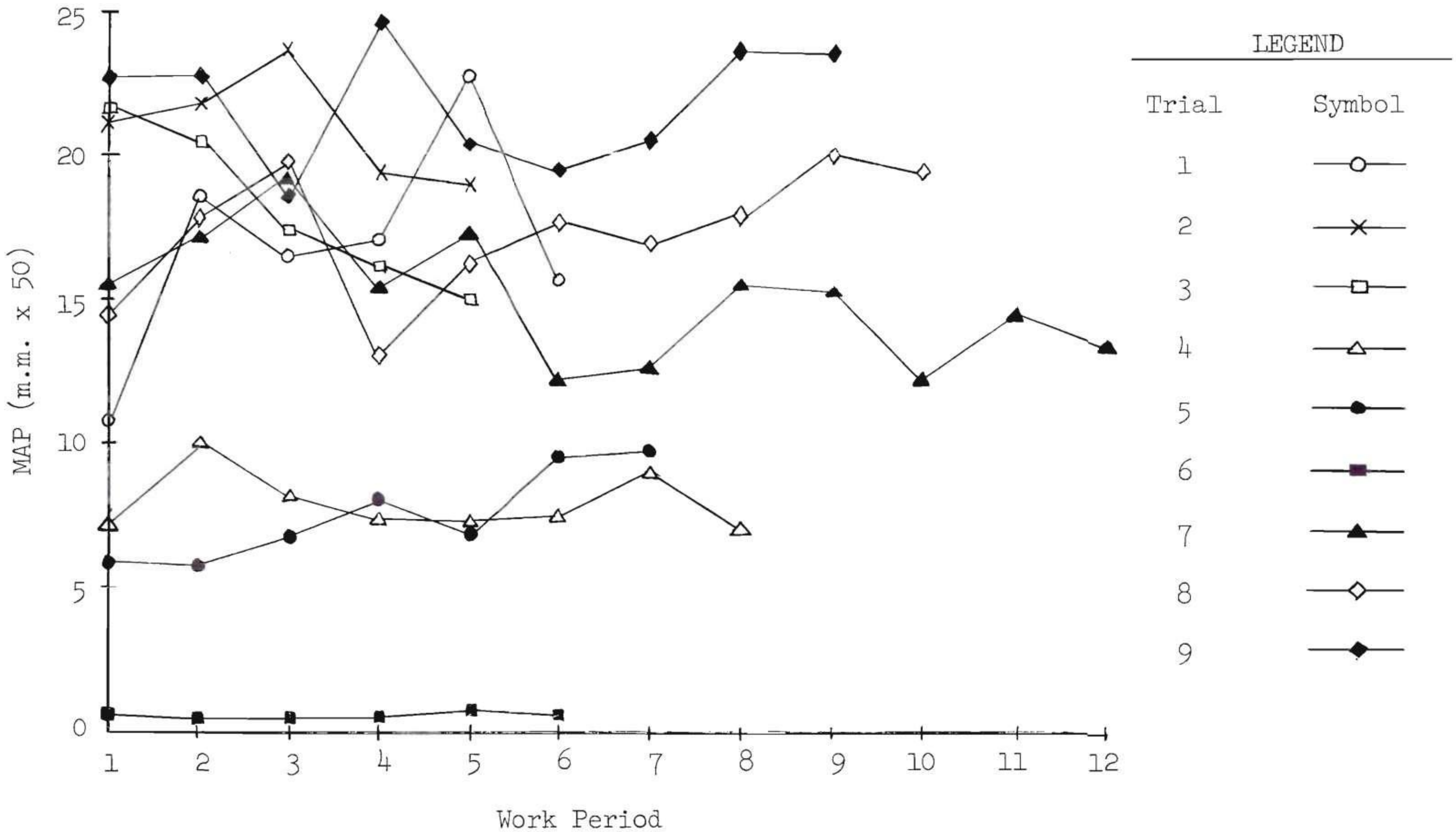

Figure 13. Average Work Period MAP for each Trial - Subject No. 3

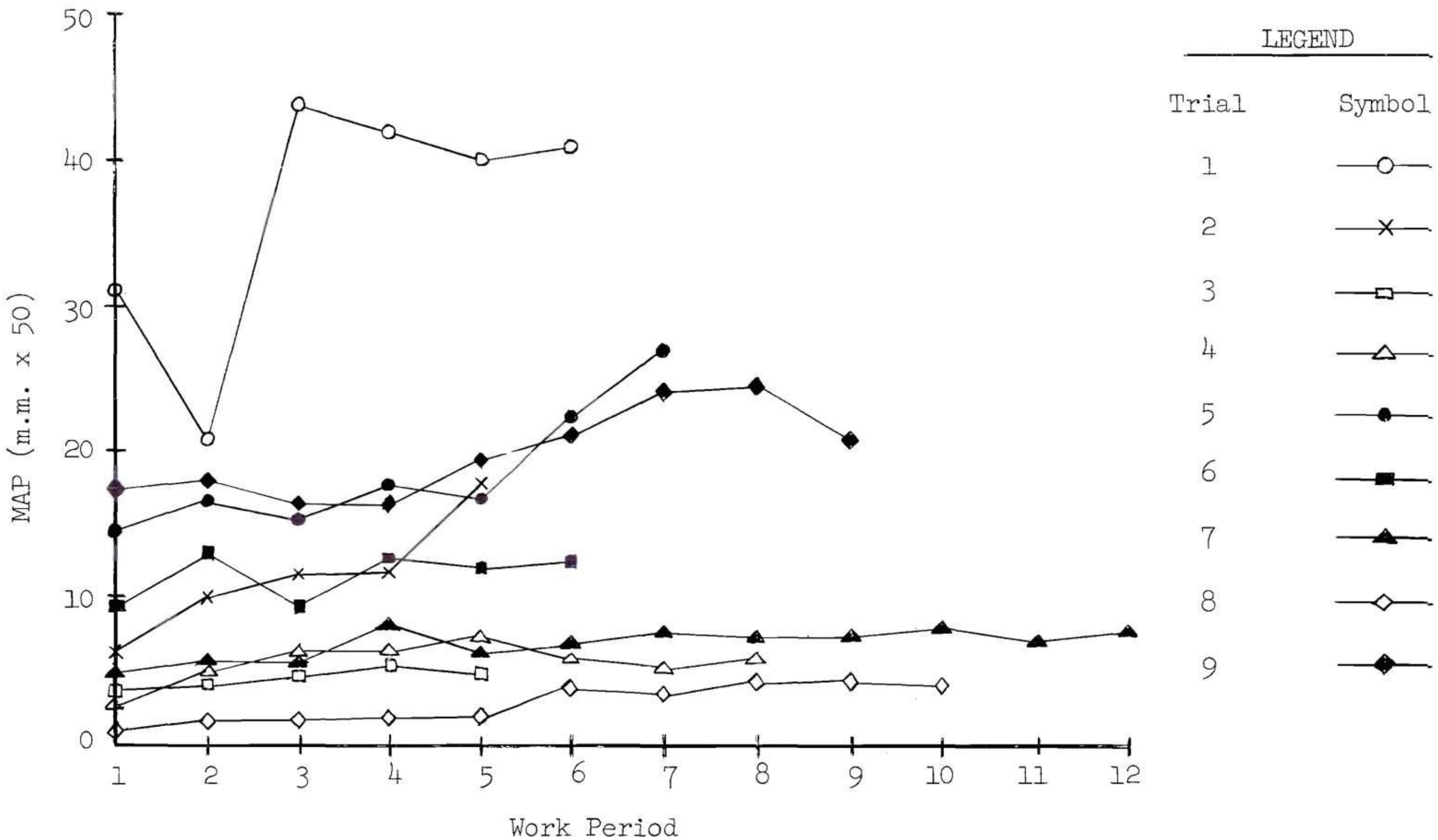

Figure 14. Average Work Period MAP for each Trial - Subject No. 4

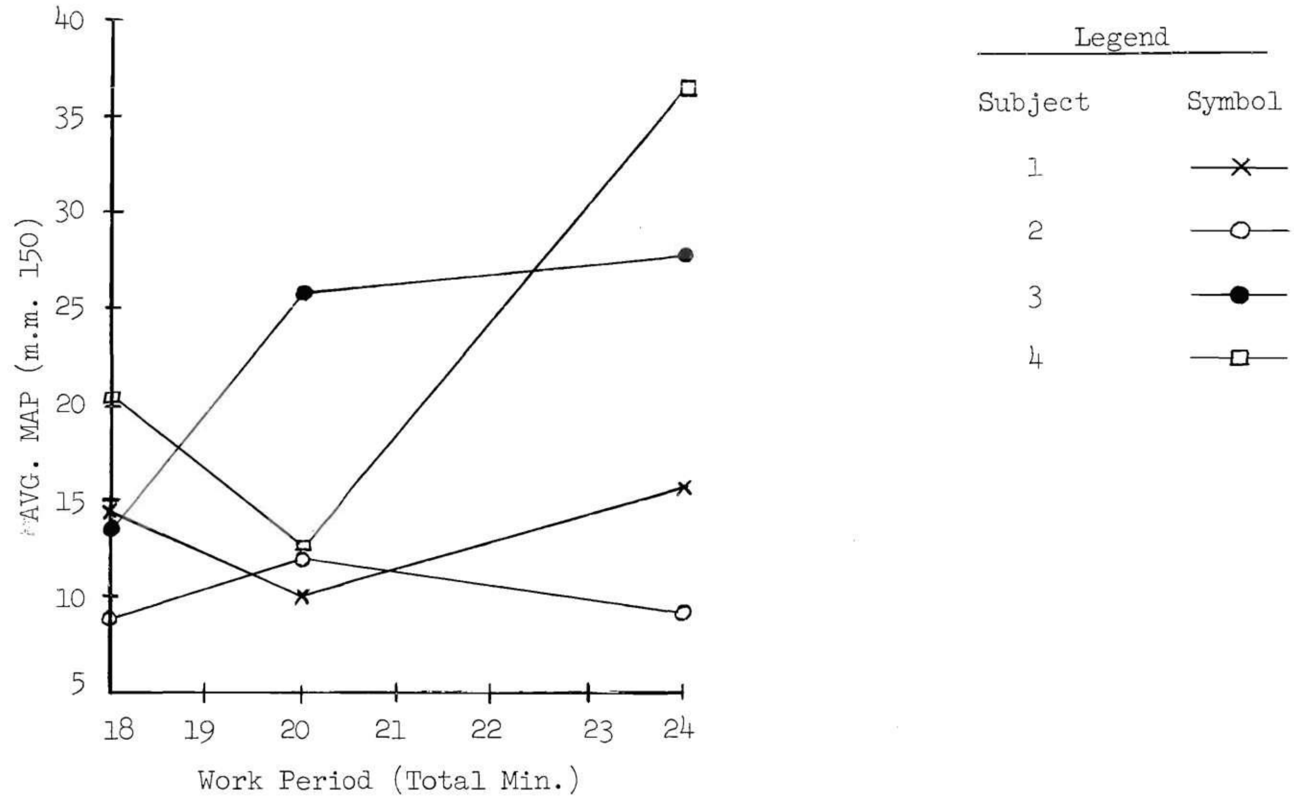

Figure 15, Average Final Map for Three Work Levels

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The results of this research indicate that the muscle action potentials in the forearm flexor muscle are not valid indicators of the physiological cost of work under the conditions imposed by these experiments. The fact that slight significant variation in the MAP's was evident for work periods; and no significant variation was evident for rest periods, subjects, and interactions between work periods, rest periods, and subjects seems to be related to the apparent large random error in the experiment. The large random error may indicate that the amplitude of the MAP's is a random process under conditions of alternating work and rest periods. The possibility also exists that under a work situation where the muscle has even the slightest chance to relax between work peaks, such as a slight inactivity between contractions, the MAP's are not affected by increasing impairment in the muscle, i.e. the muscles have a very efficient recuperative ability.

Another source of random error appears to be the variation within the subjects. It was expected that significant variation would exist between the subjects, which the analysis did not verify, but it was not expected that a large variation would exist within the subjects on different trials. It is felt that this variation was a major source of random error. Perhaps a more precisely controlled group of subjects, both mentally and physically, would have eliminated some of this variation.

It is recommended that longer periods of work and rest with varying work rates be studied over a greater range than was used in this experiment. Since only the forearm flexor muscles were investigated in this research the possibility also exists that other muscles, or groups of muscles, may produce MAPs which would be valid predictors of physiological cost, under conditions of dynamic work.

While lack of significance prevented further analysis, the author feels that the approach used to establish the work and rest periods, i.e., rest period as a percentage of work period and work period as a percentage of a base work period, may still be valid for establishing an optimum work-rest cycle. It is recommended that other physiological variables which have already been shown to be indicators of physiological cost of work, such as galvanic skin response and heart rate, be examined under experimental conditions with various work-rest periods as described above.

APPENDIX

PART I

CODED MUSCLE ACTION POTENTIAL DATA
(IN M.M.)

		R_1	R_2	R_3
S_1	W_1	91	64	99
	W_2	55	86	60
	W_3	114	142	57
S_2	W_1	129	73	157
	W_2	80	67	111
	W_3	243	153	200
S_3	W_1	174	201	85
	W_2	0	66	69
	W_3	210	163	143
S_4	W_1	34	104	363
	W_2	104	178	42
	W_3	191	13	57

PART II

CODED SUMS OF SQUARES DATA FOR ANALYSIS OF VARIANCE COMPONENTS

$$\sum_{i=1}^{I} T_{i}^{2}\cdot\cdot = 4,474,910.00$$

$$\sum_{k=1}^{K} T^{2}\cdot\cdot_{k} = 6,162,796.00$$

$$\sum_{j=1}^{J} T^{2}\cdot_{j}\cdot = 5,828,974.00$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K} T_{i\cdot k}^{2} = 1,673,726.00$$

$$\sum_{j=1}^{J} \sum_{k=1}^{K} T^{2}\cdot_{jk} = 2,173,673.00$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} T_{ij}^{2}\cdot = 1,537,973.00$$

$$T^{2}\cdot\cdot\cdot = 17,455,684$$

$$\sum_{ijk} x^{2}_{ijk} = 670,936.00$$

PART III A.

AVERAGE WORK PERIOD MAP FOR EACH TRIAL
(IN M.M.)

Subject 1

Trial	1	2	3	4	5	6	7	8	9	10	11	12
1	17.5	17.8	13.4	16.5	19.0	16.8	x	x	x	x	x	x
2	9.3	8.9	6.5	8.4	8.2	x	x	x	x	x	x	x
3	19.0	13.8	12.5	13.3	10.9	x	x	x	x	x	x	x
4	12.2	12.2	12.6	12.2	12.4	11.9	10.4	12.3	x	x	x	x
5	7.8	8.0	6.6	8.4	7.7	7.5	8.0	x	x	x	x	x
6	10.1	11.4	9.4	7.1	7.7	8.1	x	x	x	x	x	x
7	28.9	21.5	20.8	21.0	21.8	22.3	19.9	23.5	19.6	19.7	16.8	15.9
8	18.9	13.6	15.8	17.6	19.0	16.5	17.7	16.4	14.9	13.0	x	x
9	24.8	25.6	28.1	24.0	28.0	24.9	22.9	25.4	24.0	x	x	x

Subject 2

Trial	1	2	3	4	5	6	7	8	9	10	11	12
1	11.6	11.8	13.5	7.8	10.7	10.2	x	x	x	x	x	x
2	7.2	9.4	7.6	6.3	6.4	x	x	x	x	x	x	x
3	10.1	11.3	9.9	12.1	7.2	x	x	x	x	x	x	x
4	9.4	7.5	6.6	6.5	6.3	6.4	6.7	6.9	x	x	x	x
5	10 9	11.2	9.9	7.8	8.5	9.1	9.6	x	x	x	x	x
6	7.5	6.8	7.1	5.2	5.9	6.5	x	x	x	x	x	x
7	8.2	8.1	7.4	7.6	6.2	6.7	6.1	6.1	6.4	5.7	5.5	6.5
8	5.8	15.1	18.7	17.2	15.9	16.1	16.6	14.4	16.5	16.0	x	x
9	14.3	11.5	12.5	13.3	11.8	10.6	9.5	12.3	15.5	x	x	x

PART III B

Subject 3

Trial	Work Period 1	2	3	4	5	6	7	8	9	10	11	12
1	11.0	18.7	16.5	17.0	23.7	16.0	x	x	x	x	x	x
2	21.5	22.2	23.6	19.4	18.7	x	x	x	x	x	x	x
3	21.7	21.0	17.6	16.8	15.0	x	x	x	x	x	x	x
4	7.2	9.9	8.3	7.6	6.9	7.0	8.6	6.9	x	x	x	x
5	6.0	5.9	6.9	8.0	6.5	9.2	9.9	x	x	x	x	x
6	0.9	0.7	0.6	0.6	1.9	1.5	x	x	x	x	x	x
7	15.9	17.6	19.0	15.7	17.1	12.4	13.1	16.0	15.3	12.9	14.7	13.6
8	14.6	17.9	19.5	13.2	16.6	17.5	16.8	17.7	19.9	19.0	x	x
9	23.0	23.3	18.2	24.8	20.3	19.4	21.0	23.9	23.8	x	x	x

Subject 4

Trial	Work Period 1	2	3	4	5	6	7	8	9	10	11	12
1	31.7	20.9	45.7	43.9	40.3	41.2	x	x	x	x	x	x
2	5.7	10.0	11.6	11.7	17.8	x	x	x	x	x	x	x
3	3.1	4.2	4.4	5.3	4.5	x	x	x	x	x	x	x
4	3.1	4.7	5.2	5.4	6.2	5.6	5.2	5.7	x	x	x	x
5	14.3	16.4	15.1	18.3	17.6	23.1	13.2	x	x	x	x	x
6	9.4	12.9	9.7	13.2	11.2	11.8	x	x	x	x	x	x
7	4.1	5.4	4.9	7.9	5.8	6.4	7.4	7.0	7.3	8.4	7.3	8.6
8	0.9	1.2	1.0	1.2	1.2	3.3	3.0	3.6	3.8	3.5	x	x
9	16.5	17.0	15.7	17.7	19.6	22.8	24.7	24.9	21.7	x	x	x

PART IV

AVERAGE FINAL MAP FOR THREE WORK LEVELS
(M.M. x 50)

Work (Min.)	1	2	3	4
24	15.6	8.6	28.1	37.2
20	9.8	12.2	25.6	12.3
18	14.2	8.1	13.7	20.1

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